December 15, 2003

Robert J. Robertson
Environmental Affairs Director
Virginia Manufacturing Association
700 East Main Street S-1600
Richmond, Virginia 23218

Re: Virginia Manufacturers Association Comments on Dumps Creek Draft TMDL

Dear Mr. Robertson:

In response to your letter of June 23, 2003, we are responding to your questions and concerns on the Dumps Creek aquatic life TMDL. As you know, DEQ and DMME are committed to meeting the TMDL schedule contained in the Consent Decree and maintaining the technical integrity of the TMDL. Also, we are constantly looking at innovative and better methods to enhance the process. Technical review and feed back from the stakeholders and industries impacted by the TMDLs is essential to developing TMDLs that result in the attainment of water quality goals and minimize the impact on the stakeholders and industries.

In 2001, a thesis was completed at Virginia Tech that proposed a stressor / benthos relationship could be established by multiple regresssion techniques. Application of a statistical approach to determining critical stressors and water quality endpoints is a way to provide more objectivity to the benthic TMDL process. DEQ and DMME discussed this innovative approach with EPA Region III and EPA agreed to using the regression method for only the development of the Black Creek and Dumps Creek TMDLs. Currently, the reference watershed method is being used for all of Virginia's biological TMDLs.

To date, biological TMDLs have resulted or will result in at least 7 effluent limitations being placed in VPDES permits upon reissuance. Prior to and during TMDL development we supplementing the biological data with targeted chemical data. All biological TMDLs have diurnal DO monitoring to determine the impact of nutrients.

Also, stream toxicity tests are conducted for all biological TMDLs. Other targeted monitoring is done as needed.

You express concerns in which DEQ translates the general standard in biological TMDLs and this translation effectively changes the standard which should trigger the public rule making process. Also, you state that EPA has emphasized that states should develop translators for converting narrative criteria into numeric criteria. This is a monitoring issue and the following response was provided by DEQ's biological monitoring group.

> *Response: DEQ has successfully identified impairments relative to narrative standards without a numeric translator. The narrative standards have gone through the public process and will continue to be used in the assessment as described in the assessment guidance manual.*
>
> *EPA's water quality standards regulation allows for a state's water quality standards regulation to contain both narrative and numeric criteria; it does not require a regulatory translator for narrative criteria.*
>
> *Virginia has a narrative criterion that designates all state waters for the use of "the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them...". DEQ has conducted biological monitoring of Virginia's waters for many years using the EPA based RBP II methods. These methods were the current EPA recommended methods to be used in TMDL development for benthic macroinvertebrate impairments. The RBP II method was recommended by EPA during the 1990s and are still used by many states and assessing aquatic life use. EPA has required DEQ to use the results of the biological monitoring program to assess the aquatic life use in past 303(d) assessments and is requiring DEQ to use these data during the TMDL process also. EPA has in essence accepted DEQ's biological monitoring methods and the resulting data as the translation of Virginia's narrative criterion. Through the TMDL public outreach DEQ's biological monitoring methods are subjected to public review and comment many times.*

Also, VMA has expressed a number of technical concerns contained in an attachment to the letter. Many of these technical issues concerning validation, fit, and cause and effect relationship are the same or similar to those raised by EPA. Rather than address each issue individually, we are attaching a response paper dated November 5, 2003, that was prepared by Map Tech and sent to EPA. This paper addresses most of the technical issues contained in your attachment. In addition, it reflects the DEQ and DMME staff position on the regression method.

DEQ and DMME will continue to use the EPA recommended comparative watershed method for the development of all biological TMDLs. We have no plans to use the regression method in the immediate future . However as we gain knowledge and understanding of the relationship between stressors and the biological community, we plan to re-visit the regression method sometime in the future and will request EPA approval to use the method for another TMDL. We will notify VMA when we propose a change from the current method.

We appreciate the time and effort you put into developing these constructive comments. This input is essential to maintaining the integrity of Virginia's TMDLs.

Sincerely,

George Joey O'Quinn
Special Projects Inspector
Department of Mines, Minerals, & Energy
Division of Mined Land Reclamation

Nancy T. Norton, P. E.
Regional TMDL Coordinator
Department of Environmental Quality
Southwest Regional Office

Attachment

1715 Pratt Drive - Suite 3200
Blacksburg, VA 24060
540-961-7864

November 5, 2002

Re: Review of General Standard TMDL Development for Black Creek, Wise County, Virginia

This letter is in response to the document titled "REVIEW OF GENERAL STANDARD TMDL DEVELOPMENT FOR BLACK CREEK WISE COUNTY, VIRGINIA," dated August 2, 2002. We have considered the concerns expressed in this review and standby our assertion that the Black Creek TMDL represents an implementable plan for restoring Black Creek, and provides an improved procedure for developing general quality TMDLs in areas where resource extraction has impacted water quality. All new technologies in the field of water quality modeling are intended to be a step closer toward a perfect representation of the physical system. The best of these new technologies are typically critiqued based on their failure to meet this ultimate goal, but are accepted in the end based on their usefulness in moving the technology forward and the balance they reach between perfect representation of the physical system and practical use of existing technology and data. The procedures developed for determining the Black Creek TMDL are a step forward in water quality modeling and present a workable balance between complete certainty and practical use of available data.

In reviewing the use of regression models for development of a general standard TMDL for Black Creek, Wise County, Virginia, it is important to keep in mind the context of the study. The reviewers considered the context to be a purely theoretical exercise. In actuality, the context was development of a TMDL with all of the associated constraints (i.e. the limitations of existing technologies/methodologies, data availability, challenging schedules for TMDL development, and limited financial resources). In addition to this, specifically in the case of general quality TMDLs developed in Virginia, existing methodologies have been called into question. Previous TMDLs developed for biological impairments in Virginia have been criticized by stakeholders as seeming to lack objectivity. These TMDLs were developed using a reference watershed approach, whereby critical stressors are determined based predominantly on best professional judgment and a reference watershed (i.e. a similar watershed where the aquatic community is not impaired) is selected through a similar approach and represents a single combination of factors that will conceivably result in a health aquatic community. The levels of the critical stressor(s) in the reference watershed become the de-facto standard for the selected stressor(s), without regard to the levels of other stressors in the impaired or reference watersheds. This approach offers no method for assessing the uncertainties involved in selecting critical stressors and reference watersheds. Application of a statistical approach to determining critical stressors and water quality endpoints is an effort to lend more objectivity to the process. The ability to assess uncertainties involved in the use of the procedures should be considered a benefit and not used as a tool to discredit the process.

The application of regression analysis to the problem was never considered to be basic research to explore the biological function of the benthic macroinvertebrate community. The regression analysis was completed as part of a TMDL development with a fixed budget and timeframe. As such, it was an applied research project with the primary goal of developing a model that would be applicable in the Black Creek watershed, and a secondary goal of setting the stage for development of a model to apply more broadly in the Appalachian coalfields region. The effort was to be based on existing data from all available sources, and to be applicable to a general quality impairment as defined by the current assessment methods employed by the Commonwealth of Virginia.

The importance of context in assessing a proposed methodology for application in the development of TMDLs can be demonstrated by reviewing three examples. First, fecal coliform has been consistently modeled as a dissolved water quality constituent using HSPF. In fact, the case study for developing fecal coliform TMDLs presented on USEPA's web site indicates the use of the dissolved-quality-constituent functionality within HSPF to model fecal coliform (http://www.epa.gov/waterscience/ftp/basins/docs/BAS_CS1.pdf). However, modeling fecal coliform as a dissolved constituent has long been questioned in the water quality modeling community. Just this year, the Academic Advisory Subcommittee appointed by the Virginia Department of Environmental Quality to examine issues related to the development of bacteria TMDLs, pointed out monitoring efforts that indicate adsorption of bacteria to sediment. Second, while HSPF is arguably one of the best available models of its kind, it has limitations. It does not model the spatial relationships of land uses well, nor does it model the water column in multiple dimensions. In fact, each land use is modeled as contributing directly to the stream reach or reservoir without regard for the effects of runoff flowing from one land use through another before reaching the stream, and each stream reach or reservoir is modeled as one essentially homogeneous element. While other available models are better at modeling these effects, they, too, have limitations. Third, the reviewers themselves point out the limitations of using a single reference watershed as a baseline for assessing stream health, but the same consultants, through use of the reference watershed approach for developing general quality TMDLs, continue to use a single reference watershed to assess biologically impaired stream segments (e.g. the Blacks Run and Cooks Creek TMDLs). This method of using a single reference watershed to dictate a single combination of stressors that will be allowed as the target of the TMDL provided a compelling reason for exploring alternatives.

In all three of these situations, a less-than-perfect technique is being applied because of the context of application. Data availability, challenging schedules for TMDL development, and limited financial resources mandate that available, cost-effective techniques be used for their development. So, in spite of long-standing anecdotal evidence and increasing monitored evidence that fecal coliform would be better modeled as a sediment associated pollutant, modeling as a dissolved constituent continues to be accepted as an adequate approximation. In the context of producing TMDLs, HSPF has been accepted as the best model available with the understanding that, if a more comprehensive model becomes available, the new model is likely to gain favor over HSPF. Similarly, the reference watershed approach for developing general standard TMDLs continues to be used. While the reference watershed methodology is currently accepted as adequate for TMDL development, it is anticipated that the methodology proposed in the Black Creek TMDL will be an improvement on it, and that additional improvements to the process can and will be made.

In reviewing the process applied for Black Creek, there are two issues in question; 1) application of the regression approach in development of the Black Creek TMDL, and 2) widespread application of the approach in the Appalachian coalfields region. With the development of the Dumps Creek TMDL, MapTech is continuing to refine the regression models to result in models that are generally applicable in the Appalachian coalfields region. The suggestions provided by Tetra Tech are addressed as they apply to the Black Creek TMDL and as they apply to the ongoing development of a more generalized model. Each section of the review is addressed in the following paragraphs.

Much of the criticism leveled at the Black Creek TMDL is based in theoretical statistics. Theoretical statistics often assumes the availability of an unlimited dataset that describes every possible situation, and homogeneously covers the full range of values that can be associated with the data. In applying statistical methods to field observations, this is virtually *never* the case. Less than perfect data should not, however, deter the application of statistical approaches, provided that the results are applied with due caution. It is important to remember the sources of data that were available. Biological, chemical and physical data were compiled from the Black Creek drainage as well as from similar areas in southwest Virginia and eastern Kentucky. Data was collected from mine permit compliance monitoring, and from studies conducted by VA Tech (i.e. Dr. Cherry's work), VADEQ, and VADMME. The data was collected from impaired and non-impaired streams. Data availability was limited, as paired biological and physiochemical data was needed for the study.

Overfitting

While overfitting is an important concern in developing generalized models intended to be universally applicable, it is a minor issue (and is rarely considered) in water quality modeling for watershed-specific TMDLs. In fact, models are calibrated by adjusting model parameters that are sometimes seasonally variable and oftentimes outnumber the observations used for calibration. In development of the regression models used in the Black Creek TMDL, protection against overfitting was addressed at an appropriate level with regard to the application, with development of an accurate model for Black Creek being the primary goal. The reviewers state that:

> *Overfitting occurs because any independent variable added to a regression model – even a totally unrelated variable, such as <u>the stock market change</u> for the day a sample was taken – will increase R^2.*

The review indicates five suggestions regarding overfitting, each of which is addressed here.

1) Use an ↦ Value Lower than 0.25

Statistics teachers like to point out that ludicrous regressors (e.g. "the stock market change for the day") will, from time-to-time, have statistically significant relationships with the dependent variable(s) of interest simply due to random fluctuations (i.e. coincidence). An important point to remember in examining the Black Creek analysis is that clearly unrelated regressors (such as "the stock market change for the day") were never and *would never be* considered as potential stressors. In fact, all of the independent variables considered have been shown to either be related to the health of aquatic life, or good indicators of acid mine drainage (which has been shown to be detrimental to aquatic life). Because of the nature of the dataset – missing values of some parameters for some observations – an effort was made to include as many observations as possible at every step. Thus, independent variables that had more observations were tested first, so that more records could be used in assessing the strength of their relationship with the biometrics. In order not to throw out parameters at these initial stages that may have a stronger relationship in association with other parameters that had fewer observations, a relatively high $\mapsto$ value (0.25) was used. However, given that there was empirical evidence to show that all of the parameters assessed in this process had some relationship with the health of the benthic community, this alpha level was considered to be adequate.

2) Use (n/10) or (n/20) Instead of (n/2-10) as the Criterion for the Maximum Number of Parameters

Ott (1988) recommends that the maximum number of parameters used in a multiple regression model should not exceed half the number of observations minus ten (n/2 – 10). This was the rule of thumb applied in developing the regression models for Black Creek. While this was the criterion, the actual number of parameters in the models ranged from approximately n/4 to n/9. While a more restrictive rule of thumb could have been used, one goal of this study was to describe the relationship of benthic health to multiple stressors that were already known to be related to benthic health, so that various implementation options could be assessed. Our goal was to produce a model that would allow the production of implementable TMDLs, as opposed to a theoretically idealistic but impractical model.

3) Use Additional Statistics to Measure Overfitting

Sequential R^2, Akaike's Information Criteria (AIC), Mallow's C(p) and the residual mean square of the model have been suggested as potentially useful measures to guide selection of parameters. But, as stated in the review, they are more suitable for use in a forward selection of variables than in backwards or stepwise selections. Since all three methods of selection were considered – in an attempt to consider as many potential models as possible – the statistics suggested would have had limited use. Mallow's C(p) is focused on in the review, and is a measure of the relationship between the error resulting from use of the full model (including all potential stressors) and the error resulting from the model under consideration. In the case of this study, the full model results in zero error (a perfect, though overspecified, fit), and makes Mallow's C(p) mathematically indefinable. The results described in the review consider only the last step in a series of steps designed to consider all of the potential stressors. As such, the results presented are not valid in examining the procedures used for the Black Creek project.

4) Consider Normality, Independence, and Collinearity

As suggested in the review, normality and independence become particular concerns when statistical hypotheses and confidence intervals are being constructed with regard to the regression results. Because the end goal of this process was to produce accurate bioassessments, which are calculated based on ratios of the modeled biometrics (regression results) and scoring based on the ratios falling in a particular range of values, knowledge of confidence in the regression results was viewed as being of secondary importance to confidence in the final bioassessment. Because of the scoring process, confidence in the final bioassessment could be higher than confidence in the regression model results. Since this level of statistical assessment (i.e. hypotheses and confidence intervals) of the regression models was not viewed as critical in this application, normality and independence were not viewed as highly significant factors. In addition, independence in field observations, particularly in environmental studies, is virtually *never* achieved. Since factors such as climate and geographical relationships (e.g. upstream and downstream relationships) cannot be controlled, observations can almost never be viewed as independent. In fact, independence is not desirable if the cumulative impact of influences compounding downstream are to be considered. In this context, the data was as independent as possible and the existence of some dependence among observations was not considered to be problematic.

Collinearity was addressed by assessing correlation between independent variables, as stated in the review, additionally the model building procedures used (i.e. backward, forward, and stepwise regression) are designed to include only the more significant terms when collinearity exists. The “problem” presented by collinearity is that two or more related independent variables (e.g. Mn and Fe) may each have a fairly weak relationship with the dependent variable (e.g. taxa richness) when both are included in the model because there is an overlap of impacts. If Mn has a collinear relationship with other parameters that went undetected, the modeled relationship may be weaker than the actual relationship, resulting in a greater reduction being required, which adds an implicit margin of safety (MOS) to the allocation. Another concern when considering collinearity is that the resulting model may be hard to interpret because one needs to consider potential implementation scenarios and the likely impact on related (collinear) water quality parameters if one parameter is addressed. In the application to Black Creek, these potential interactions were considered and addressed. For instance, the proposed implementation strategy for Black Creek is re-mining. Through re-mining the source of acid mine drainage is reduced. So, reducing Mn inputs to the stream will likely result in reductions of Fe, sulfate, total dissolved solids, conductivity, and acidity, resulting in an additional implicit MOS.

5) Avoid Extrapolation

In applying the regression models, modeled observations of water quality parameters were evaluated to determine if the values fell within the range of values used to develop the regression models. If one of the modeled values fell outside of this range, then the observation was not used. This process eliminated the possibility of extrapolation. Under allocation conditions, 87% of the modeled observations were used. None of the scenarios tested reduced the number of usable observations as they were designed to bring stressors to more moderate levels.

Validation

The usefulness of validation has been debated since the earliest stages of modeling. A successful validation certainly gives the impression of a successful modeling effort. However, typically, unless positive validation results are obtained in the first attempt, the model calibration is revisited or, in the case of statistical models, alternative models are tested until the best validation results are achieved. In the end, all available data have been used to build the model. In a case where there is a paucity of data, as was the case during the development of the Black Creek TMDL, it makes more sense to use all available data from the beginning to build the model. As more data become available and the biometric models are refined, various methods of validation can and are being pursued.

Scientific Credibility of the Models

In assessing the scientific credibility of the Black Creek study, the reviewers focused on broad application of the results and the traditional constraints of theoretical statistics. It is important to restate the context of the study in addressing the issues raised. The model framework was developed primarily for application to the Black Creek TMDL and, secondarily, as a stepping-stone to more widespread application. Additionally, this was not an exercise in theoretical statistics. It was an effort in applied research to develop the most applicable models for Black Creek. In this context, concerns about broader application of the models or adherence to statistical traditions are diminished.

There are three main points made in this section:

1) The model should accurately reflect what is known about the response of the aquatic community to stressors.

A sensitivity analysis was performed during the Black Creek study to examine the response of the modeled bioassessment to changes in stressor levels. This analysis was performed in the particular context of the Black Creek watershed and a similar analysis should be performed if these or similar models are applied in other watersheds. An initial base run was performed using observed chemical data from Black Creek's reference station (i.e. UBC-1) and a target station in the lower Black Creek (i.e. LBC-4). Perturbations to the base condition at the target station for each stressor were made and entered in the biometrics models, producing a bioassessment score relative to the reference station. This analysis displayed the trends that would be expected (e.g. increasing sulfate levels resulted in decreasing bioassessment scores), and validate the use of the existing model in Black Creek. As the model is developed further, the response of specific metrics can be examined in detail to improve confidence in the model at this more refined level.

2) The identification of manganese as a measurement of the mitigation effort is troublesome.

There are two reasons given in the review for a manganese allocation being troublesome. First, manganese in and of itself has not been shown to be as toxic as some other metals. Second, reductions based on manganese would be “hard to sell.” Regarding the first reason, while manganese has shown chemical toxicity to aquatic organisms only at relatively high values, manganese toxicity was never identified as a key stressor mechanism for Black Creek. Manganese precipitates may physically impair habitat, reduce periphyton productivity, and impair respiration. Additionally, manganese levels have long been used as a relatively inexpensive measure of the “strength” of acid mine drainage. In a recent study, Soucek et al. (2002) found that aluminum, which has historically been considered benign in waters with circum-neutral pH levels, can form persistent, fine precipitates with the potential to clog the gills and reduce respiration of some species (e.g. the perlid stonefly, *Acroneuria*). This impact may have gone unnoticed because of toxicity testing that only considers the chemical impacts to an individual, albeit representative, species. The data that MapTech has compiled for the Black Creek study may point to a similar impact. As stated before, manganese levels remain a good indicator of impacts from acid mine drainage. This is why it is used as an indicator for permit compliance, and this is why it has a strong relationship with the health of the benthic community. In the Black Creek watershed, manganese is more closely correlated to Zn, Pb, and Al than Fe is. Because of these relationships, Mn levels are a good indicator of metals other than Fe that are present in the water column.

3) Including linear, log, and squared terms is troublesome.

In the traditional application of statistics, the main reason for applying transformations is to develop an independent variable that has a normal distribution. Given this perspective based on theoretical statistics, it may therefore seem illogical to include more than one transformation or a linear term and its transformation. However, since we have already established that normality is not the highest priority in this application, the reason for transformations is to develop a model that more closely reflects the relationships being modeled. Most researchers would agree that, given the complexity of biological systems, linear models are either oversimplified or reflect only a narrow range of situations. Figure 1 shows a slide presented by MapTech to the reviewers showing some biological responses to stressor levels. The mathematical representation of these curves would have to include combinations of linear, log, and squared terms, in addition to higher-order polynomials.

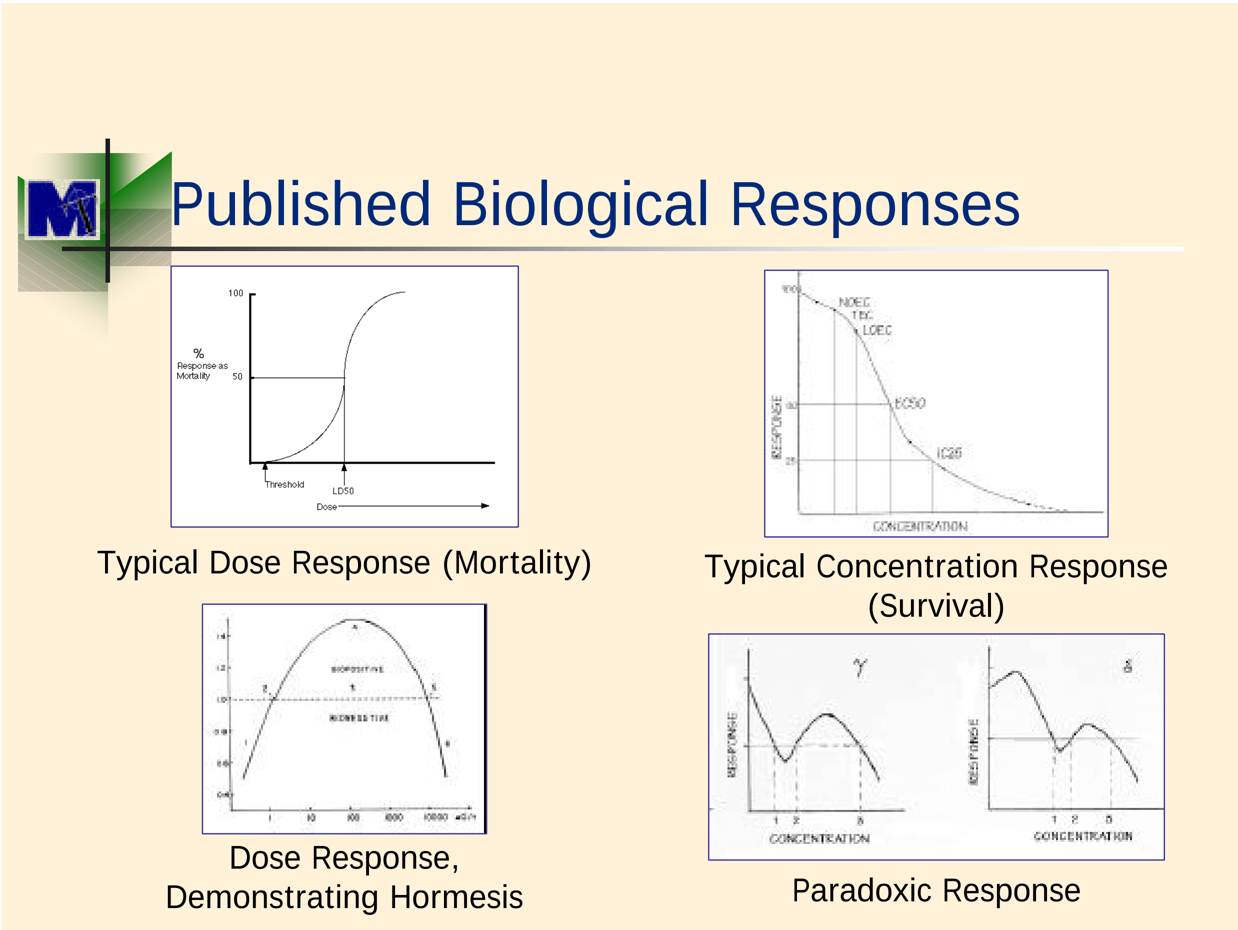

Figure 1. **Slide presented by MapTech at meeting held at the VADEQ regional office in Woodbridge, Virginia, on July 9, 2002.**

Other Issues

The use of a modeled 85% bioassessment score was called into question based on three points:

1) A single reference station is used for the analysis, rather than a regional reference target.

The information from multiple reference stations has been incorporated into the overall analysis procedure by using data from multiple reference stations in the regression analysis. Thus, multiple scenarios are available in terms of defining water quality goals. The use of a single reference station in the development of the Black Creek TMDL was based on the fact that the commonwealth of Virginia currently uses a single reference station to assess target streams. It was beyond the scope of this study to evaluate/rewrite the Commonwealth's biological assessment methods. Rather, it was the goal of this study to mimic the existing assessment methodology, thus increasing the reasonable assurance of successful implementation.

2) This may not be an "implicit" margin of safety.

It may be more appropriate to refer to the margin of safety as "explicit" rather than "implicit" as it is a specific increase of the bioassessment criterion.

3) The inclusion of site-specific control sites in the analysis of reference stations and the use of an average bioassessment score as an endpoint may not result in a conservative endpoint.

Six records in the database used referred to site-specific control sites. These records were removed and the analysis was repeated (Figure 2). The average bioassessment score dropped from 85.0% to 84.7%. Given that the current criterion for de-listing a General Quality impaired stream in Virginia is a bioassessment score of 50% (indicating a slightly impaired condition) an endpoint of 85% is believed to be adequately conservative. Using this criterion, the lowest modeled bioassessment score for the allocated condition was 54%, with 96% of scores falling above 71%, the historic criterion for listing.

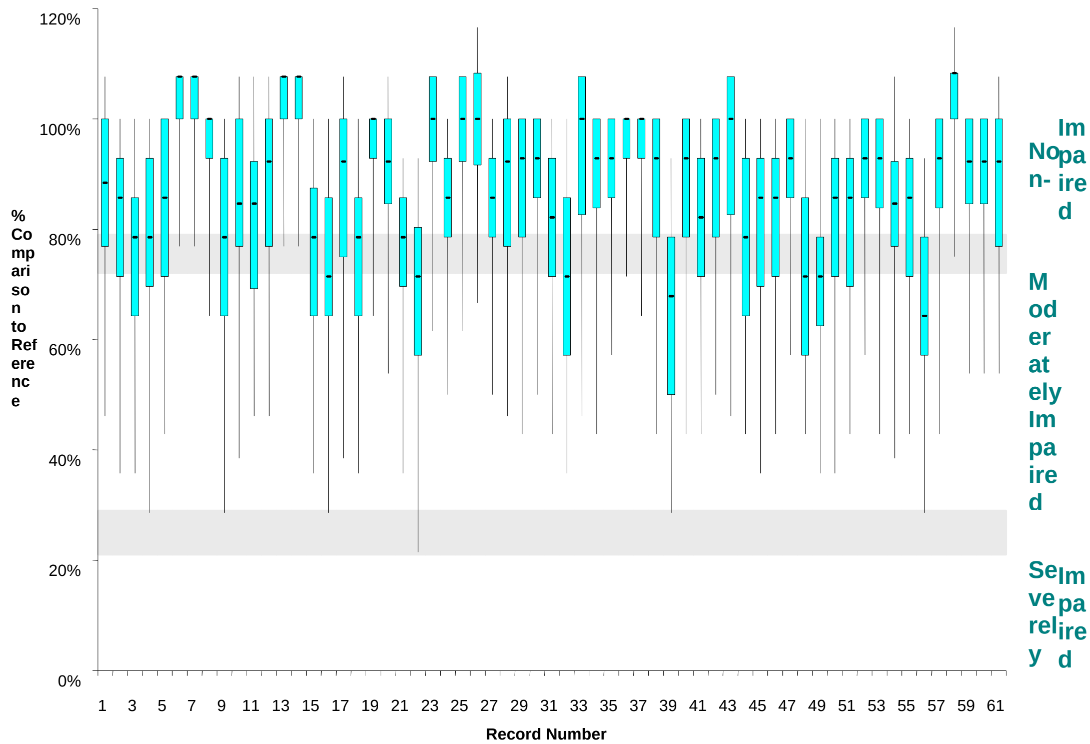

Figure 2. Comparison of bioassessment variability in VADEQ established reference stations.

Another question raised by the reviewer has to do with the naming of the procedure:

Why use the term "multiple-parameter approach" instead of the more usual "multiple regression"? A parameter is, technically, a measure of central tendency or spread. A variable is actually a characteristic that changes among entities. They are using multiple variable regression models; everyone uses multiple parameters.

This statement reflects the reviewer's focus on theoretical statistics. Within the realm of statistics his definitions are reasonably accurate, and the development of the relationship between biometrics and stressors was indeed an exercise in multiple regression. However, the name chosen reflects the broader application of the procedures developed. *The American Heritage Dictionary* (2000) gives five definitions for parameter, as follows:

1. *Mathematics.* A constant in an equation that varies in other equations of the same general form, especially such a constant in the equation of a curve or surface that can be varied to represent a family of curves or surfaces.

2. *Mathematics.* One of a set of independent variables that express the coordinates of a point.

3. One of a set of measurable factors, such as temperature and pressure, that define a system and determine its behavior and are varied in an experiment.

4. A factor that determines a range of variations; a boundary: *an experimental school that keeps expanding the parameters of its curriculum.*

5. *Statistics.* A quantity, such as a mean, that is calculated from data and describes a population.

Within the field of water quality, the term "parameter" often refers to a characteristic of a water body (e.g. a pollutant level), corresponding to the third definition listed. Our naming refers to the capability of the procedure to consider the cumulative impact of multiple water-quality parameters on aquatic health, in contrast to other procedures that consider the impact of water-quality parameters individually.

The final concern deals with a statement in the report that only 7 of 100,000 scenarios met the target:

> *…the authors stated that they tried 100,000 different scenarios and only 7 met the target improvement to 85% of reference metric score. Assuming the most liberal of natural error, wouldn't you expect more than 7 by just chance alone? Certainly 7 seems within the realm of simple chance. This seems to argue against these models as necessarily non-random or universally applicable.*

The assessment of scenarios was composed of an automated process that stepped through more than 100,000 combinations of reductions to identify any that resulted in at least an 85% average bioassessment, and a manual process to hone down the initial set of identified scenarios. The first step produced many scenarios that were essentially duplicates; e.g. if a 50% reduction of a constituent worked, then 60%, 70%, 80%, 90%, and 100% reductions would also work (provided the reduction did not result in extrapolation of the biometric models). The final set of seven scenarios were selected manually to avoid duplication, and to establish a more precise reduction. The resulting scenarios are a subset of the infinite number of all working scenarios (i.e. any scenario resulting in an 85% or greater average bioassessment score), and represent some of the scenarios that meet, but do not exceed, the 85% criterion.

Conclusion

Upon careful consideration of the concerns expressed in this review, we maintain our confidence in the Black Creek TMDL and its legitimacy as a first step toward restoring Black Creek. Further, the techniques described in the document constitute an improved procedure for developing general quality TMDLs in areas where resource extraction has impacted water quality. Context is important. Many of the concerns presented in the review have their place in theoretical applications, however, in the context of the Black Creek TMDL (and all other TMDLs) pure theory is not applicable. The state of technology is always such that researchers do not know everything. However, the engineering profession has a long history of applying the best practical approximation to produce a workable solution to a given problem. The procedures developed for determining the Black Creek TMDL are a step forward in water quality modeling and present a workable balance between complete certainty and practical use of available data.

References

Ott, L. 1988. An Introduction to Statistical Methods and Data Analysis: Third Edition. PWS-Kent Publishing Company, Boston, MA.

Soucek, D.J., D.S. Cherry, and C.E. Zipper. 2002. Impacts of mine drainage-associated aluminum in circum-neutral pH surface waters of the North Fork Powell River. Presented at the Regional Coalfield Water Resource Symposium, University of Virginia's College at Wise. September 4, 2002. http://www.vwrcc.vt.edu/publications/example.html

The American Heritage Dictionary. 2000. *The American Heritage® Dictionary of the English Language*: Fourth Edition, Boston: Houghton Mifflin Company